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SEISMICITY AND RECENT FAULTING IN EASTERN CALIFORNIA AND  
WESTERN AND CENTRAL NEVADA - A PRELIMINARY REPORT

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WESTERN AND CENTRAL NEVADA: A  
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16. Abstract ERTS-1 imagery covering the eastern California-Nevada seismic belt were utilized to study the fault pattern in relation to the distribution of earthquake epicenters and Quaternary volcanic rocks. Many suspected faults not previously mapped were identified. These include several suspected shear zones in Nevada, faults showing evidence of recent breakage, and major lineaments. Highly seismic areas are generally characterized by Holocene faulting and Quaternary volcanic activity. However, several major fault segments showing evidence of recent breakage are associated with little or no seismicity. The tectonic pattern strongly suggests that the eastern California-Nevada seismic belt coincides with a major crustal rift associated with zones of lateral shear. New data on potentially active fault zones have direct practical applications in national and local earthquake hazard reduction programs. Positive contacts have been made with Kern and Ventura Counties to make results of this investigation available for application to their earthquake hazards definition projects.					
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## Preface

### (a) Objective

A major objective of this investigation is to assess the utility of ERTS-1 imagery in identifying significant geological structures in the southwestern United States and to interpret their tectonic implications.

In the first six-month period (Abdel-Gawad and Silverstein, 1972, 1973) we concentrated on seismic areas of the San Andreas and Transverse Range systems of Central and Southern California. Our preliminary studies of ERTS-1 imagery suggest that it is often possible to identify geomorphic evidence of recent fault movements. When we consider that recurrence of fault movements is a common phenomenon, the ability to identify fault zones showing evidence of recent activity would help define seismically hazardous areas. Correlation of faults with the distribution and magnitudes of historic earthquakes shows clearly that many areas which at present are seismically quiet have probably been active and may be subject to recurrence of faulting and earthquake damage.

For both scientific and practical considerations, we have continued to place major emphasis on this problem.

### (b) Scope of Work

In this report we describe observations on the fault and seismicity patterns in a belt extending from southeastern California northward into western and central Nevada. The area includes what Ryall, Slemmons, and Gedney (1966) described as the most active continuous seismic zone in the western United States during historic time. That zone extends from the California coast near Ventura to Winnemucca in north central Nevada.

The report includes:

- (1) observations derived from ERTS-1 imagery concerning the fault pattern with particular emphasis on fault zones suspected to have undergone recent breakage.
- (2) plots of earthquake epicenters and magnitudes on overlays corresponding to ERTS-1 imagery.
- (3) preliminary analysis of relationships between faulting, seismicity, and Quaternary volcanic activity.

(c) Summary and Conclusions

Earthquake epicenters were plotted on 7 ERTS-1 images covering the Nevada seismic zone of Ryall, Slemmons, and Gedney (1966) and Gumper and Scholz (1971). The seismicity pattern suggests that the California-Nevada seismic belt which generally trends north-south consists of a series of northeast-trending seismic zones arranged en echelon. We plotted known faults on image overlays and then utilized ERTS imagery to identify lineaments and probably fault structures not previously mapped. The inferred structures fall into four classes:

(1) Three relatively major fault zones similar in trend to the Walker Lane and Furnace Creek faults were recognized in central and north central Nevada. These are tentatively named the Black Butte Shear, the Austin Shear, and the Battle Mountain Fault Zone. In addition we identified many smaller faults of similar northwest-southeast trend. Many faults of this class are suspected to represent strike-slip zones of shear caused by unequal rates of extension in the Basin and Range province. We suspect that some of these shear zones may have a left-lateral component of movement, that is opposite to the sense of movement on major fault zones such as Walker Lane and Furnace Creek, Las Vegas shear, etc.

(2) North-south to north-northeast faults parallel to the main trend of the Basin and Range structures in Nevada. Although faults of this trend have long been known to characterize the main grain of the Basin and Range province, ERTS imagery contributed significantly in identifying many faults of this class which show evidence of Holocene activity. The belt containing the recent faulting coincides generally with areas of seismic activity.

(3) Northeast-southwest faults trending oblique to the Basin and Range grain. Some of these, e.g. in the Excelsior Mountain area and Slate Ridge area, are suspected to have left-lateral sense of movement. The significance of this observation within the general tectonic framework has not yet been determined.

From this investigation we found that the eastern California-Nevada seismic belt coincides with areas characterized by Holocene (recent) faulting and Quaternary volcanic activity. The distribution of historic earthquakes, Holocene faulting, and Quaternary volcanics suggests a tectonic model based

upon the concept that east of the Sierra Nevada lies an active rift belt crossed by several shear zones analogous to rift zones and transform faults on the ocean floor. The tectonic model illustrated in Figs. 11 and 12 is consistent with ideas advocated by Hamilton and Myers, 1966; Gumper and Scholz, 1971; and Thompson, 1965.

(d) Program for Next Period

In our first 6-month report we indicated (Abdel-Gawad and Silverstein, 1972, p. 21) that our plan for the second 6th month period would include extension of the work southward to the head of the Gulf of California. Instead, we elected to give priority to the California-Nevada seismic belt.

During the next six month report we plan to concentrate on geological features across the Gulf of California.

(e) Recommendations

Requested color products are being delivered to us at a slow pace. We recommend faster delivery in order for the study to make full advantage of these products.

## PRACTICAL APPLICATIONS

### General

A most important result of this investigation which has direct practical applications is the ability to recognize and map fault lines showing evidence of Holocene breakage.

Faults suspected to have undergone movement during the Quaternary Period are indicated by the symbol (R) in overlay maps.

Evidence of recent faulting in a given area can be safely considered to indicate that the area has been subject to earthquake recurrence even though the pattern of historic earthquake data may for statistical considerations not reveal such activity.

We believe that the ability to identify from ERTS imagery areas and specific lines where recent faulting is indicated can be of considerable value to both national and local programs for the evaluation of earthquake hazards and for planning corrective measures to reduce damage and loss of life.

Because the entire western third of the North American continent lies within a belt of crustal deformation, a viable program to inventory potentially active faults in such a vast and rapidly developing area by conventional field and aerial photographic methods is an endeavor of major proportions in cost, manpower availability, and time considerations. The utilization of ERTS imagery to identify and map potentially active faults can significantly reduce the cost and effort of planning detailed field investigations. Although a quantitative estimate is not available at present, ERTS imagery can conceivably reduce the total areas to be examined in detail and the cost by a factor of 100 and probably more.

#### SPECIFIC INFORMATION

The national and some states' awareness of a strong need to obtain more comprehensive data on earthquake hazards is now beginning to be felt on the county and city government levels.

1.a,b,c Contacts have been made with Ventura County Planning Commission (Victor Husbands, Planning Director) and Kern County Office of Emergency Services Commission (Ray Jackson) for the purpose of making the results of our ERTS studies available to them. Both agencies are starting programs for evaluating earthquake hazards which include as an essential element making an inventory of potentially active faults in their counties.

We intend to provide pertinent data derived from analysis of ERTS imagery available to these counties and hope to work with them towards realizing the objectives of their seismic hazards assessment programs.

The ERTS imagery data covering Ventura and Kern Counties were derived from two passes taken in August and September 1972. Previously unknown faults have been inferred from ERTS imagery, using Bands 5 and 6 and some false color products supplemented by examination of available U-2 imagery and some 1961 aerial photographs scale 1:60,000 in parts of Ventura, Los Angeles, and Kern Counties. The location of suspected faults is sufficiently accurate for detailed checking by conventional field methods.

2.a,b Assessment of costs and benefits have not yet been made. However, a reduction of ground areas to be surveyed in detail by a factor of 100 or

more appears to be a reasonable guess.

Faults on the order of 10 km or more in length are more efficiently identified in ERTS imagery than from aerial photographs. Mapping of such faults can be made to a scale from 1:1,000,000 up to 1:250,000. Although many faults shorter than 5 km can often be identified in ERTS imagery, often mapping scale considerations impose limitations on using ERTS imagery for mapping minor faults.

For the purpose of utilizing ERTS imagery to identify seismically hazardous areas, emphasis should be placed on major and medium faults which can be more efficiently mapped from ERTS imagery than by conventional geologic methods.

2.c The information derived from ERTS on the location and characterization of suspected faults can be immensely helpful to many organizations. Even the preliminary and unverified observations can be of great value in planning detailed field proving studies compatible with their specific problems and needs.

Examples of these organizations are:

State, County, and City Planning Commissions:

Seismic hazard zoning, site selection for public schools, hospitals, land development, and residential building guidelines and regulations.

Gas Companies: Location of major gas lines and potential hazards of fault movements.

Departments of Water Resources, Water Companies:

Dam site selection and safety, aqueducts and other hydraulic structures, reservoirs, and water treatment plants.

Departments of Transportation: Freeway overpasses, bridges, rapid transit facilities.

Oil Companies: Oil field pipelines and other structures.

Atomic Energy Commission, Electric and Nuclear Energy Companies:

Site selection for nuclear power plants, transformer stations, underground power lines.

Each of these organizations can use the information in one way or another in their planning process. The potential impact in long range cost savings and in minimizing damage from fault movement can be enormous.

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## Introduction

The area subject of this report is largely within the Basin and Range province east of the Sierra Nevada. It includes the northern Mojave Desert, Owens and Panamint Valleys and extends northward covering western and central Nevada (Figure 1).

ERTS-1 scenes covering this study area are:

MSS 1019-18050

MSS 1054-17594

MSS 1055-18053

MSS 1018-17592

MSS 1018-18001

MSS 1018-18003

MSS 1055-18055

## FAULTS, SEISMICITY, AND YOUNGER VOLCANIC ZONES

The tectonic style in this area suggests a close relationship between faulting, seismic activity and the distribution of Quaternary to late Tertiary volcanic rocks.

For this reason, we plotted on overlays the following data:

- a) Known faults derived from published maps and geologic reports drawn in solid lines.
- b) Suspected faults or lineaments inferred from ERTS-1 imagery and believed to be significant for the objectives of the investigation. Many of the inferred structures need to be checked and studied in the field in detail. Their identification on the overlays serves to pinpoint their suspected trace and will serve to guide interested agencies and field geologists. Faults or lineaments suspected to have been active in the Holocene on the basis of photogeomorphologic evidence are indicated by the symbol (R).
- c) Areas of known or suspected Quaternary volcanic exposures are shown for comparison (Fig. 9).

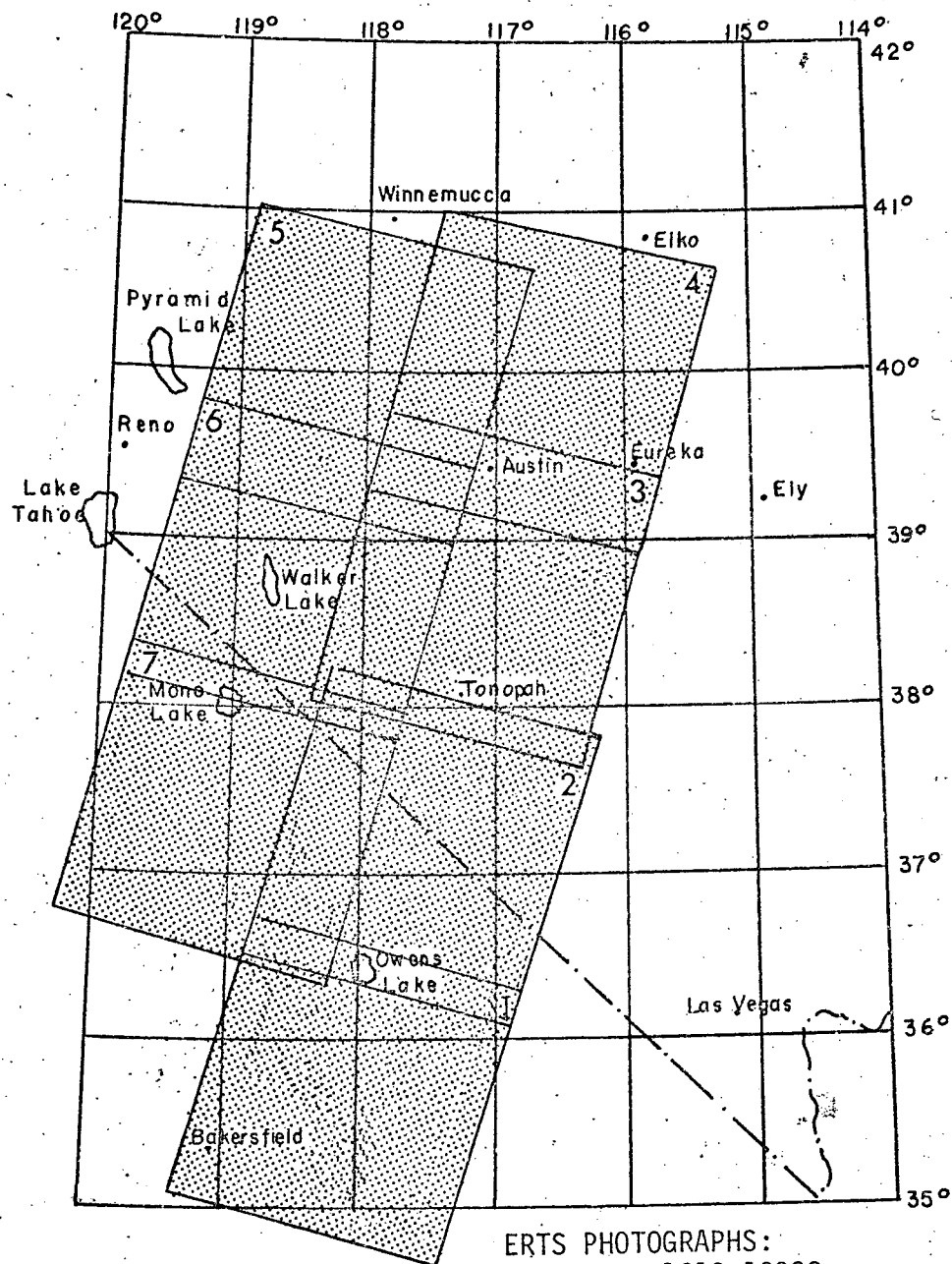
A preliminary description of significant observations for each ERTS-1 scene follows:

### SOUTHERN SIERRA NEVADA

Reference: MSS 1018-18003

Overlays: Figures 2a, 2b

FIGURE 1 MAP OF AREA STUDIED



ERTS PHOTOGRAPHS:

- #1 - MSS 1018-18003
- #2 - MSS 1018-18001
- #3 - MSS 1054-17594
- #4 - MSS 1018-17592
- #5 - MSS 1019-18050
- #6 - MSS 1055-18053
- #7 - MSS 1055-18055

1018-18003

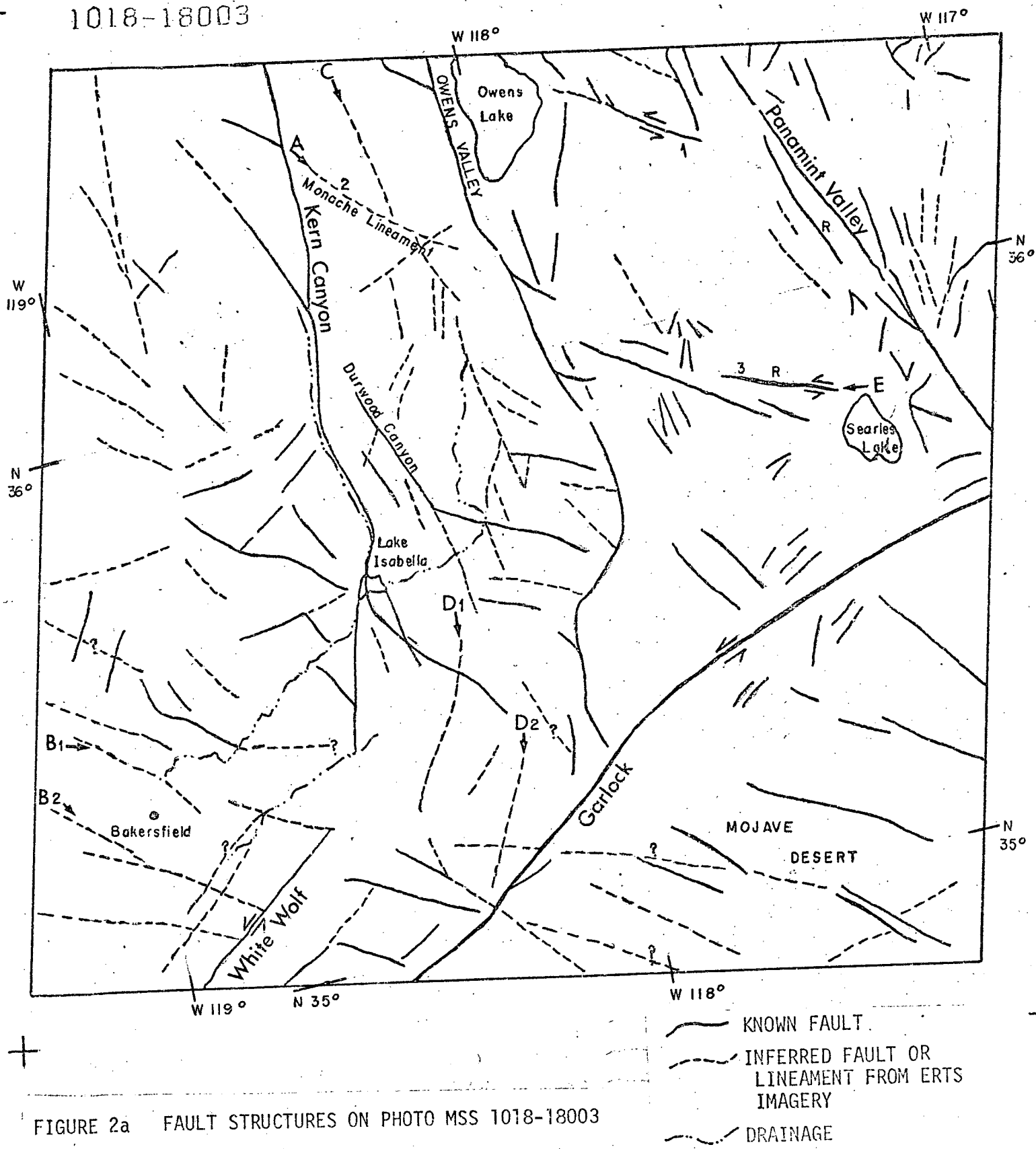
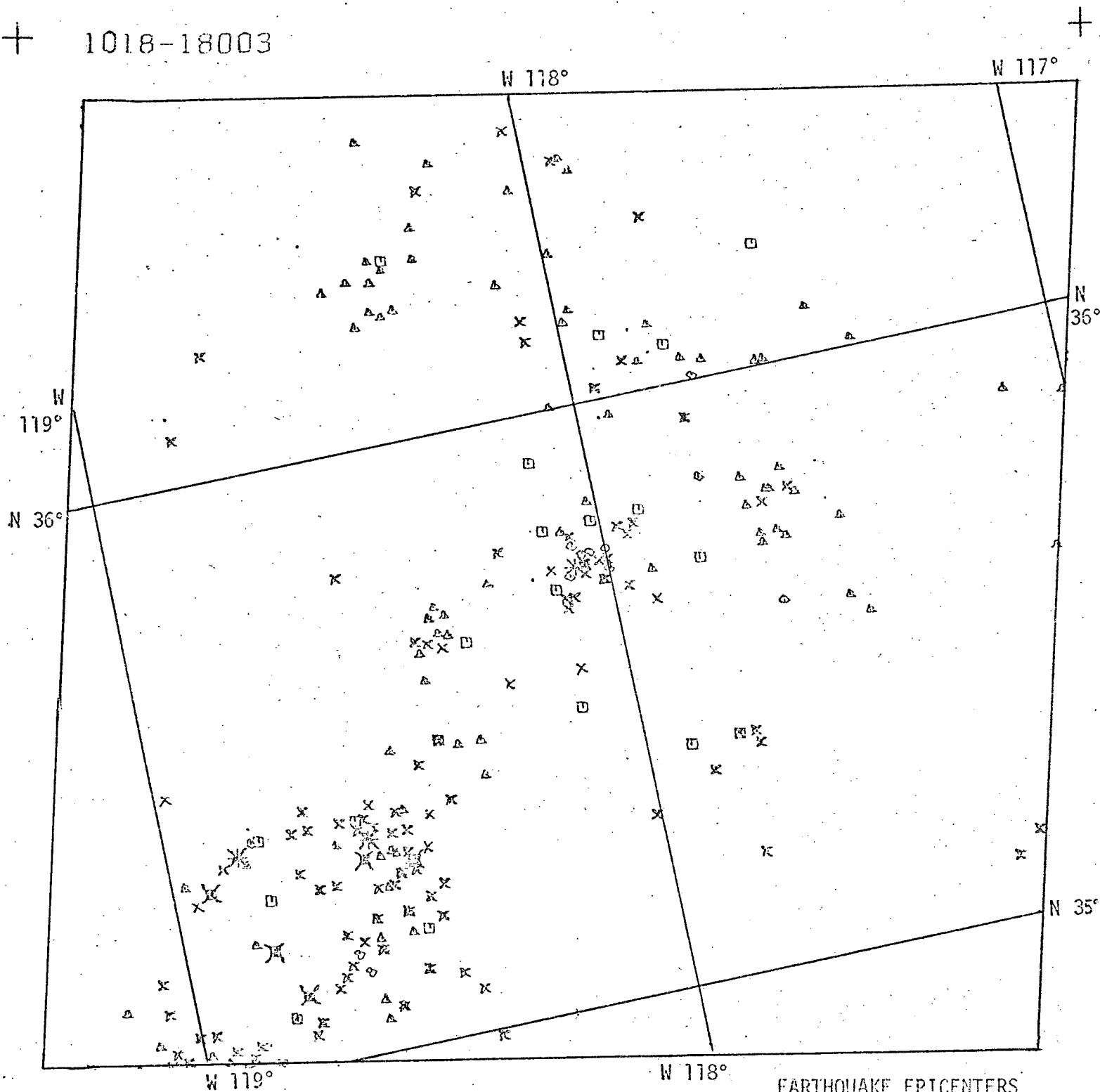


FIGURE 2a FAULT STRUCTURES ON PHOTO MSS 1018-18003

+ 1018-18003



Symbol

EARTHQUAKE EPICENTERS

Richter Magnitude

UNKNOWN

0 - 4.0

4.1 - 4.9

5.0 - 5.4

5.5 - 5.9

6.0 - 6.9

7.0 - 7.9

8.0 - 8.4

> 8.4

Figure 2b - Earthquake Epicenters Plotted on Photograph MSS 1018-18003

The scene shows the southern part of the Sierra Nevada mountains. The main known fault zones are: the Owens Valley fault zone running along the eastern scarp of the range, Panamint Valley fault, Kern River fault, Garlock and White Wolf faults. Other significant faults are identified by a key number.

The known faults in this area have the following general trends:  
North-south to NNW-SSE, e.g., Kern River, Owens, Panamint.  
Northeast-southwest, e.g., Garlock, White Wolf.

West-northwest: Known examples occur in the Mojave desert. The fault east of Owens Lake (1 Fig. 2a) is a left lateral strike-slip fault (Mayo, 1947).

In Figure 2a we recognized in ERTS-1 imagery many possible faults belonging to all three major systems which do not appear in the geological maps (Geologic Atlas of California); Bakersfield, Trona, Death Valley, and Fresno sheets.

Most of the suspected faults occur in Kern and Tulare counties. Several west-northwest trending lineaments appear to cut across the southern end of the Sierra Nevada and Tehachapi mountains almost at right angles to the Garlock and White Wolf faults. Although the Garlock fault stands out as a very prominent feature in ERTS imagery, the active White Wolf is no more prominent than west-northwest lineaments referred to. Because known faults of the same trend occur in this area, their existence should be checked in the field. They may be particularly significant because they appear to extend north-westward under the San Joaquin Valley in the vicinity of Bakersfield, California. The area east and south of Bakersfield is seismically active and lies at the intersection of three major fault systems. The Kern River fault, Garlock and White Wolf and the west-northwest system which parallels the San Andreas fault in its middle segment.

Another important fault which we refer to here as the Monache fault zone trends west-northwest and cuts obliquely across the Owens Valley extending from Searles Lake to south of Owens Lake. Several faults of this zone east of the Sierra Nevada have been previously known. ERTS imagery, however, shows that it is a continuous fault zone extending across the eastern side of the Sierra Nevada to the Kern River fault (2, Fig. 2a). This fault zone is probably older than the main eastern fault scarp of the Sierra Nevada because

the latter cuts boldly across it.

The Monache Fault zone is significant for several reasons:

a) It marks a possible continuation of an important fault zone across the faulted eastern scarp of the Sierra Nevada.

b) It marks a significant altitude difference of the Sierra Nevada blocks north and south of it. This significant altitude difference causes the block directly west of Owens Lake to show higher albedo and lighter vegetative cover in the color prints than the block directly southwest of lineament.

c) It is associated with several Tertiary volcanic centers and hot springs.

d) This fault may belong to the transverse tectonic element observed pervasively throughout California. It is significant that this transverse element persists outside the Transverse Ranges where it has been traditionally recognized.

It may be appropriate to refer to our previous reports (Abdel-Gawad and Silverstein, 1971, 1973) on manifestations of the transverse tectonic element within the Coast Ranges of California.

The seismicity pattern suggests that earthquakes tend to cluster near intersections of transverse fault zones with the other more widely recognized fault systems.

Prominent faults such as Garlock, Kern River and Panamint Valley faults are not particularly associated with earthquakes except near certain fault intersections.

East of the Sierra Nevada, earthquake epicenters tend to cluster near Quaternary and late Tertiary volcanic areas.

New major features inferred in Fig. 2a:

A. Northwest-southeast extension of the Monache fault lineament across the Sierra Nevada.

B1, B2. West-northwest fault (?) zones under San Joaquin Valley; similar lineaments appear to continue south-eastward beyond White Wolf and perhaps beyond Garlock fault as well as into the Mojave Desert.

C. Fault (?) lineament within Sierra block and parallel to its eastern escarpment.

D1, D2. Fault (?) lineaments parallel to southern segment of Kern River fault.

E. Known fault; left-lateral offset of 2-3 Km is inferred.

#### INYO AND WHITE MOUNTAINS, CALIFORNIA

Reference: MSS 1018-18001

Overlays: Figures 3a and 3b

The scene shows part of the Sierra Nevada Crest, Owens Valley between Bishop, California and Owens Lake, Inyo and White Mountains, bounded on the northeast by the Furnace Creek fault running adjacent and parallel to the California-Nevada state line and across the border part of the Basin and Range Province in Nevada.

The two major known fault zones are: The Owens Valley fault marks the eastern side of the Sierra Nevada block and has been reported to be a combination normal and strike-slip right-lateral fault with a total lateral displacement of 25 Km or less (Hamilton and Myers, 1966). The Furnace Creek fault is generally considered a north-westward continuation of the Death Valley fault. Together the Furnace Creek-Death Valley faults have been reported to be major strike-slip faults with a cumulative displacement amounting to some 80-100 Km (Hamilton and Myers, 1966).

Between these two major breaks the White and Inyo mountain block is broken by a system of north-south to NNE-SSW mostly normal faults with an evidently tensional tectonic style, as indicated by the many grabens and horsts within the Inyo-White Mountain block.

The area across the stateline in Nevada has evidently not been mapped in detail comparable to that in California. We utilized ERTS imagery to identify many linear features which will contribute to a better understanding of the tectonic style in Nevada in more detail. Known faults and probable faults derived from analysis of ERTS imagery are shown in Figure 3a.

Epicenters of historic earthquakes corresponding to Fig. 3a are plotted in Figure 3b.

The following observations are significant:

a) Sharp physiographic lineaments are observed within the Sierra Nevada block west of the crestline (A, Fig. 3a). These lineaments are not shown on



1018-18001

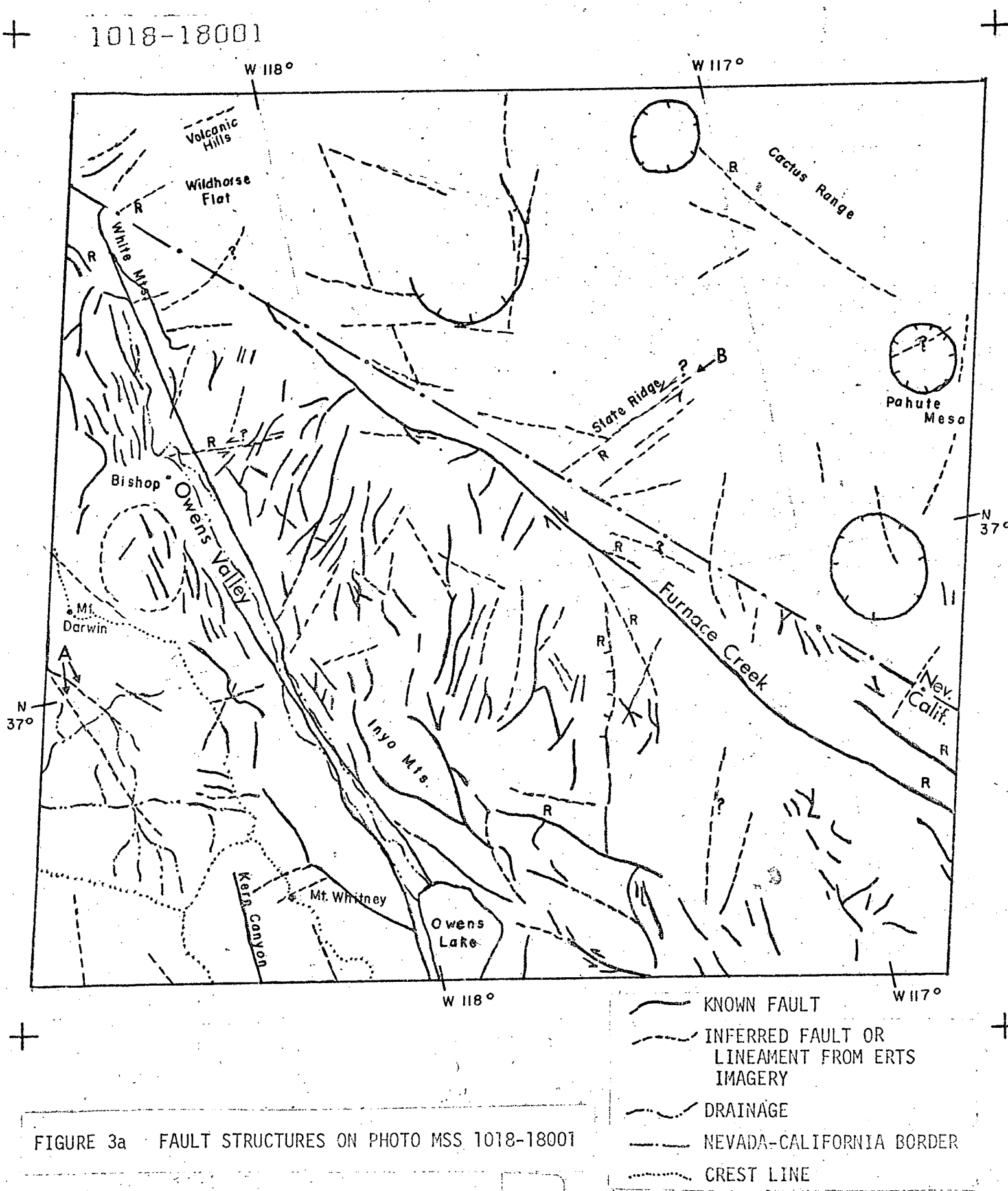
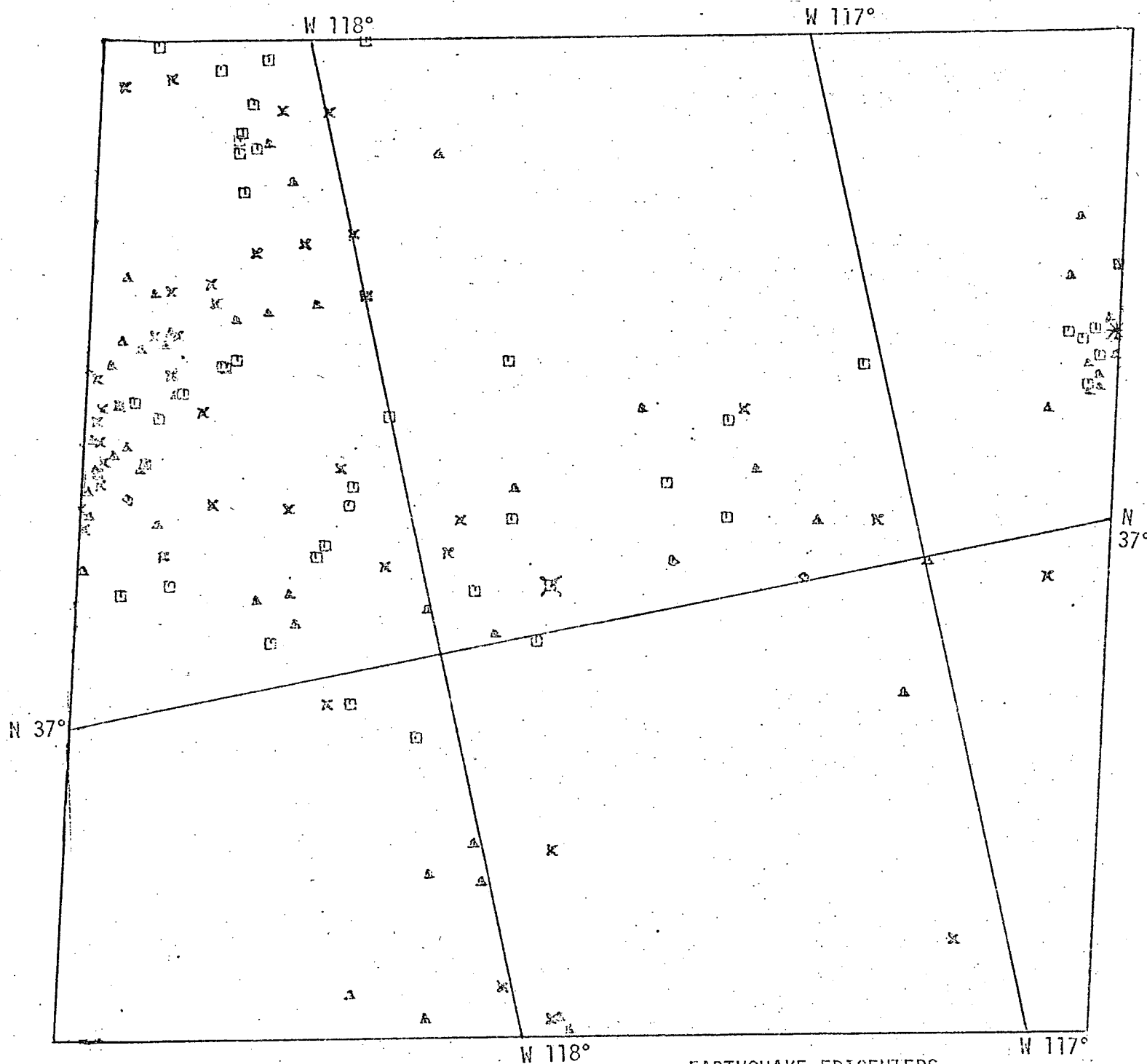


FIGURE 3a FAULT STRUCTURES ON PHOTO MSS 1018-18001

+ 1018-18001



EARTHQUAKE EPICENTERS	
Symbol	Richter Magnitude
□	UNKNOWN
○	0 - 4.0
△	4.1 - 4.9
×	5.0 - 5.4
◇	5.5 - 5.9
✕	6.0 - 6.9
✖	7.0 - 7.9
✗	8.0 - 8.4
✙	> 8.4

Figure 3b - Earthquake Epicenters Plotted on Photograph MSS 1018-18001

the Fresno and Mariposa sheets, Geologic Atlas of California. They trend northwest-southeast parallel to the Furnace Creek fault and appear more clearly on other ERTS images not masked by clouds (see for example, MSS 1055-18055).

The lineaments do correspond however to contacts between the mesozoic granitic intrusives and a Jurassic-Triassic metavolcanic belt. The linearity of this feature suggests a fault contact and should be field checked.

b) Geomorphologic evidence of recent faulting can be inferred along many fault traces belonging to at least three fault systems. Examples are indicated by the symbol R in Figure 3a.

A northwest-southeast system includes the Furnace Creek fault, the Owens Valley fault and the Cactus Range fault. A north-south fault system encompasses many smaller faults between the Furnace Creek and Owens Valley Faults, a fault running east of Fish Lake Valley and two cutting through the Cottonwood Mountains. A third system is a northeast-southwest fault system including, for example, arrow B (Fig. 3a).

c) It is noted that while some seismicity appears to be associated with the Furnace Creek fault zone and many segments of the fault zone show evidence of recent breakage, the most seismically active sites are the Pahute Mesa Caldera, Wildhorse Flat and Owens Valley, areas of subsidence due to tension with extensive development of Quaternary and late Tertiary volcanics.

#### MONO LAKE, SIERRA NEVADA, OWENS VALLEY

Reference: MSS 1055-18055

Overlays: Figures 4a and 4b

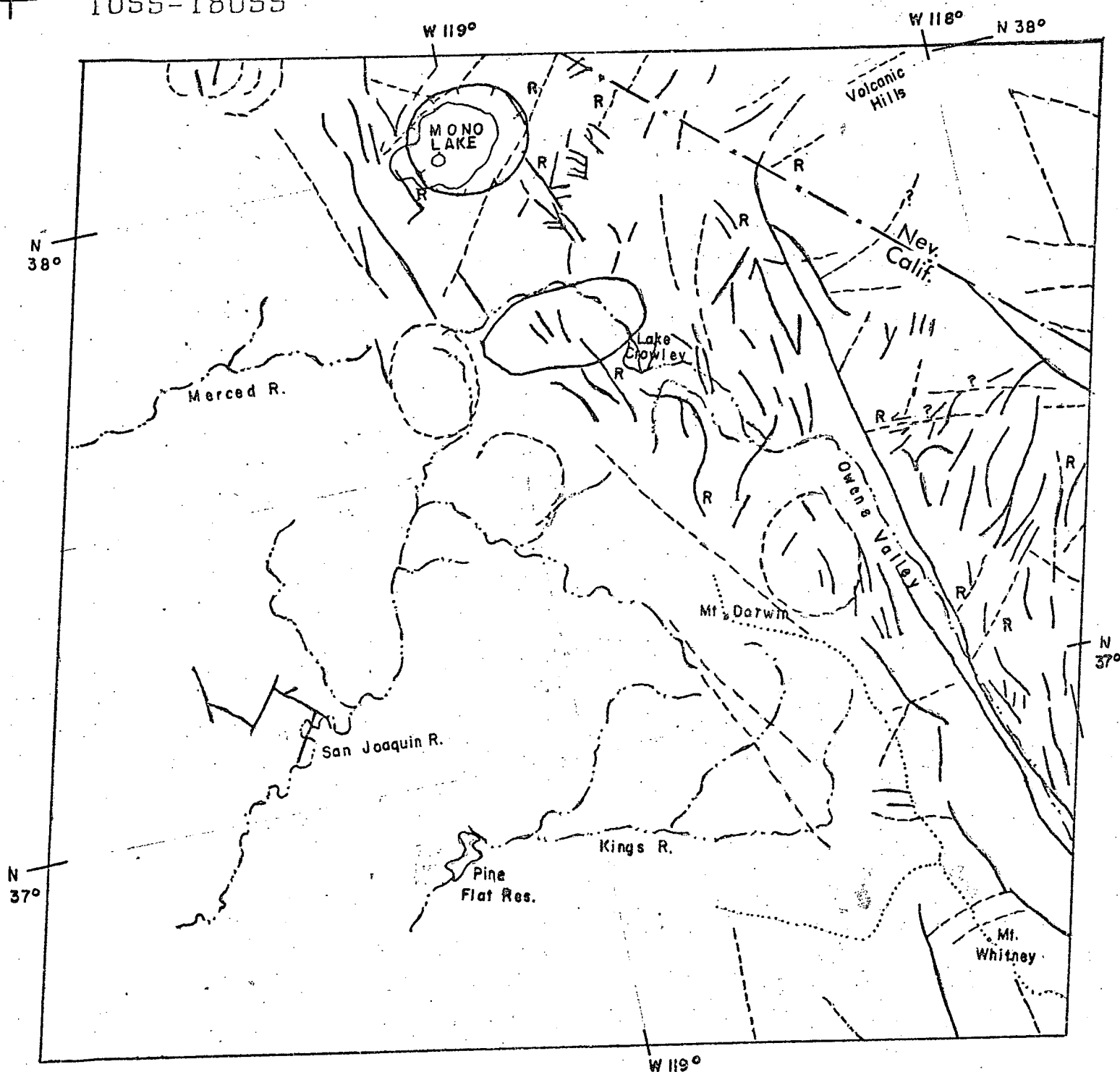
This scene covers the area from Mono Lake in the north to Mt. Whitney and the Kings River in the south. It shows the Sierra Nevada Range and the San Joaquin Valley to the west, and the Owens Valley to the east.

Known faults and the faults or lineaments inferred from ERTS imagery are shown in Figure 4a.

Four main fault systems can be recognized in this scene (Fig. 4a):

1) North-northwest trending faults are represented by the Owens Valley Fault. Sharp northwest-southeast physiographic lineaments can be seen within the Sierra Nevada block west of the crestline. They appear to run

1055-18055



- KNOWN FAULT
- - - INFERRED FAULT OR LINEAMENT FROM ERTS IMAGERY
- ~ ~ ~ DRAINAGE
- - - NEVADA-CALIFORNIA BORDER
- ... CREST LINE

FIGURE 4a FAULT STRUCTURES ON PHOTO MSS 1055-18055

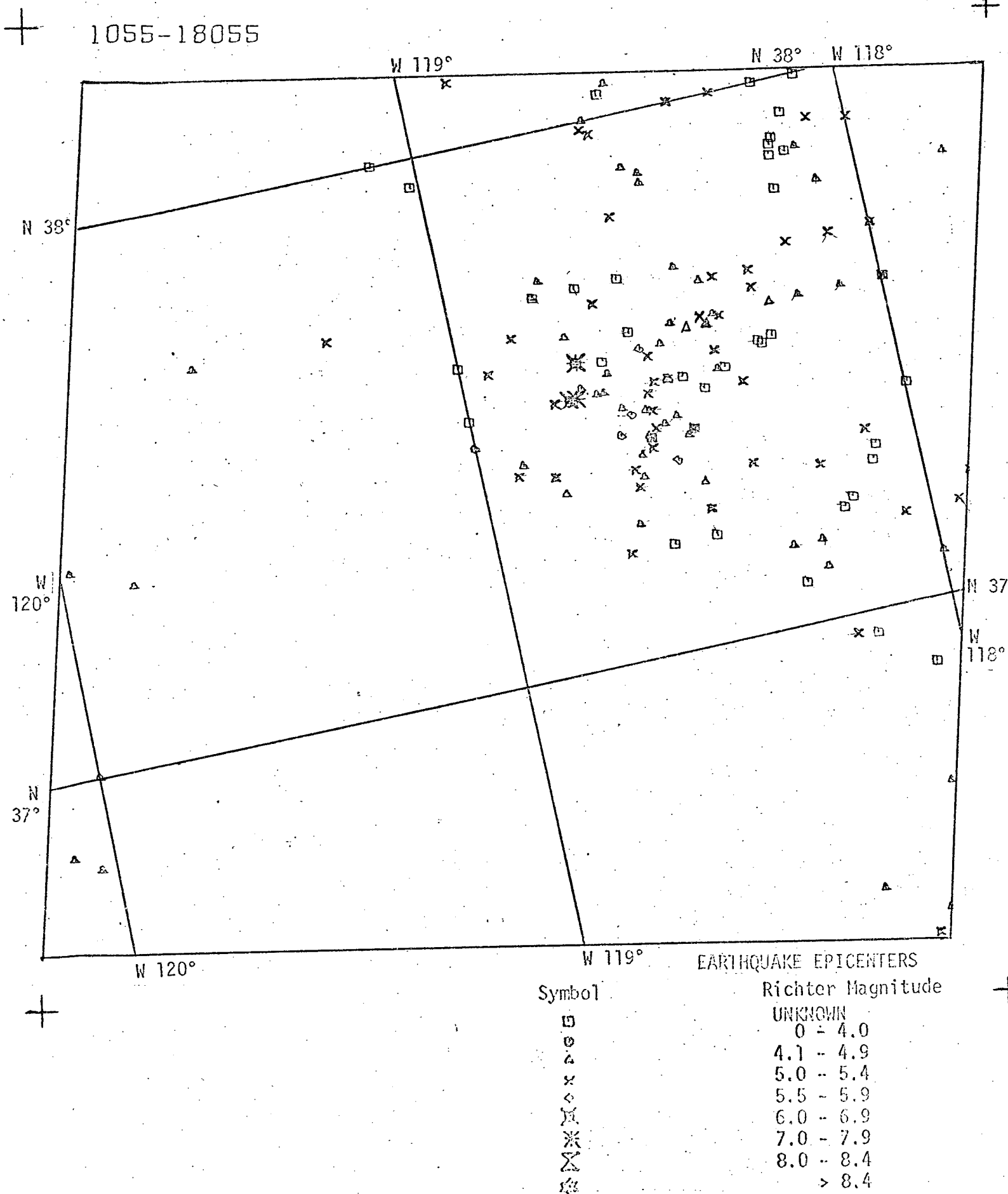


Figure 4b - Earthquake Epicenters Plotted on Photograph MSS 1055-18055

parallel to the Furnace Creek Fault.

2) The northeast-southwest faults include several showing evidence of Holocene breakage located east of Mono Lake.

3) Some of the east-west faults, such as those located east of the Owens Valley suggest fairly recent left-lateral offsets. However, there is relatively very little seismic activity which could be related directly to these faults.

4) Several circular features are observed east of the headwaters of the Merced River and the San Joaquin River, east of Mount Darwin, and west of Mono Lake.

Historic earthquake epicenters for figure 4a are shown in figure 4b.

Seismic activity is concentrated on the eastern side of the Sierras with an almost complete void of earthquake activity on the western side. The heaviest concentration of earthquakes is in the area between Lake Crowley, the Owens Valley, and the California-Nevada border. Here the cluster shows a strong northeast trend.

#### MONO-WALKER LAKES, CARSON RIVER, NEVADA

Reference: MSS 1055-18053

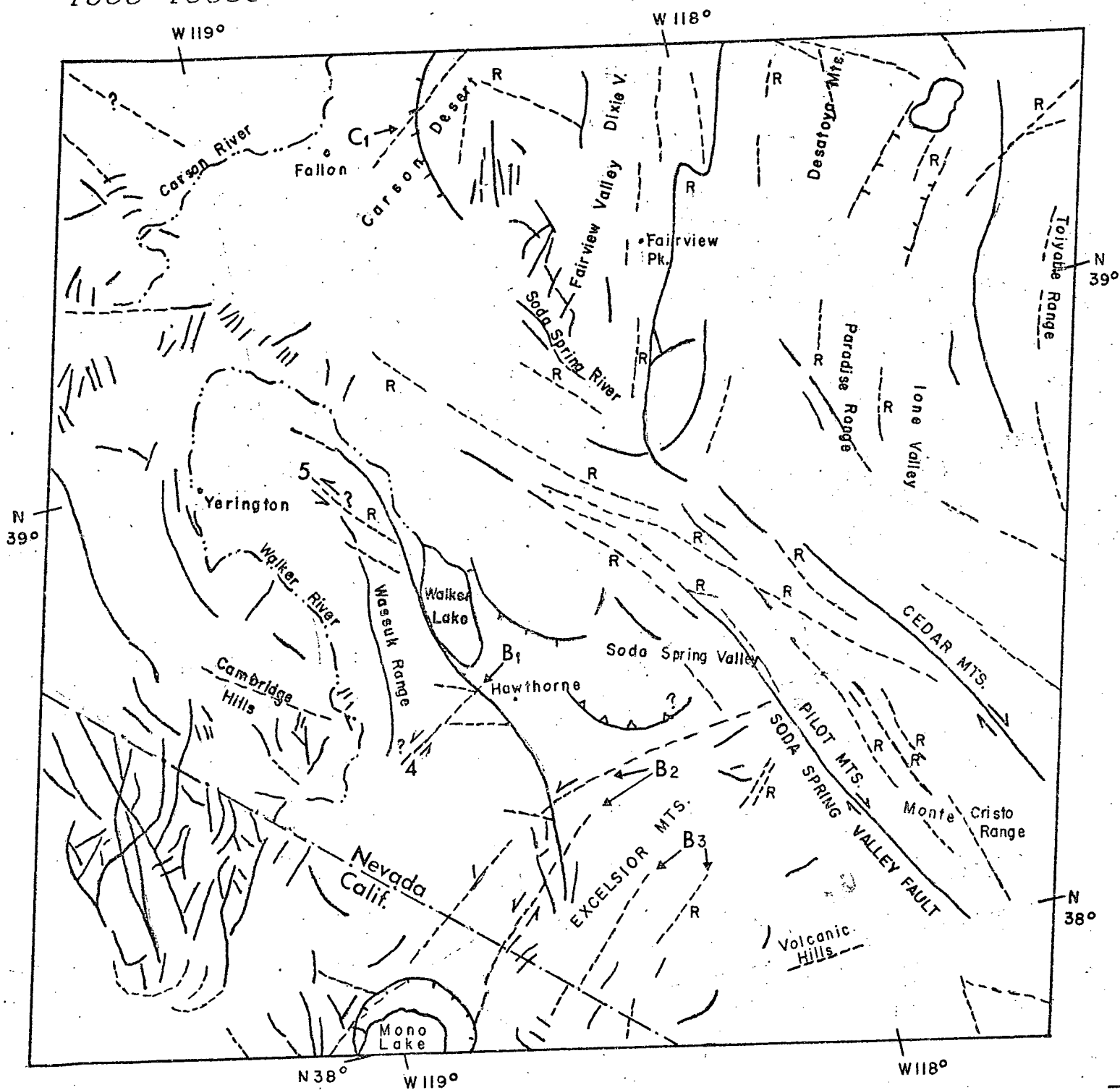
Overlays: Figures 5a and 5b

This scene is particularly important because it shows one of the most seismically active areas in the western United States and includes a large part of the Walker Lake, "a zone separating ranges where trend is mostly northward, northeast of the fault from ranges where dominant trend is northwestward, southwest of the fault" (Hamilton and Myers, 1966, p. 531). According to (Gianella and Calaghan, 1934), numerous small rifts and fissures formed during a 1932 earthquake show an echelon pattern of right-lateral displacement.

Several pre-Tertiary structures and stratigraphic units have been offset about 20 Km right-laterally within the zone (Nielsen, 1965). The Cedar mountain fault and Soda Spring Valley fault and other major known faults shown in Figure 5a are taken from King, 1969.

ERTS-1 imagery shows the Walker Lake zone as a definite major fault zone characterized by well recognized fault traces, many of which appear to be

1055-18053



- KNOWN FAULT
- - - INFERRED FAULT OR LINEAMENT FROM ERTS IMAGERY
- - - DRAINAGE
- - - NEVADA-CALIFORNIA BORDER

FIGURE 5a FAULT STRUCTURES ON PHOTO MSS 1055-18053

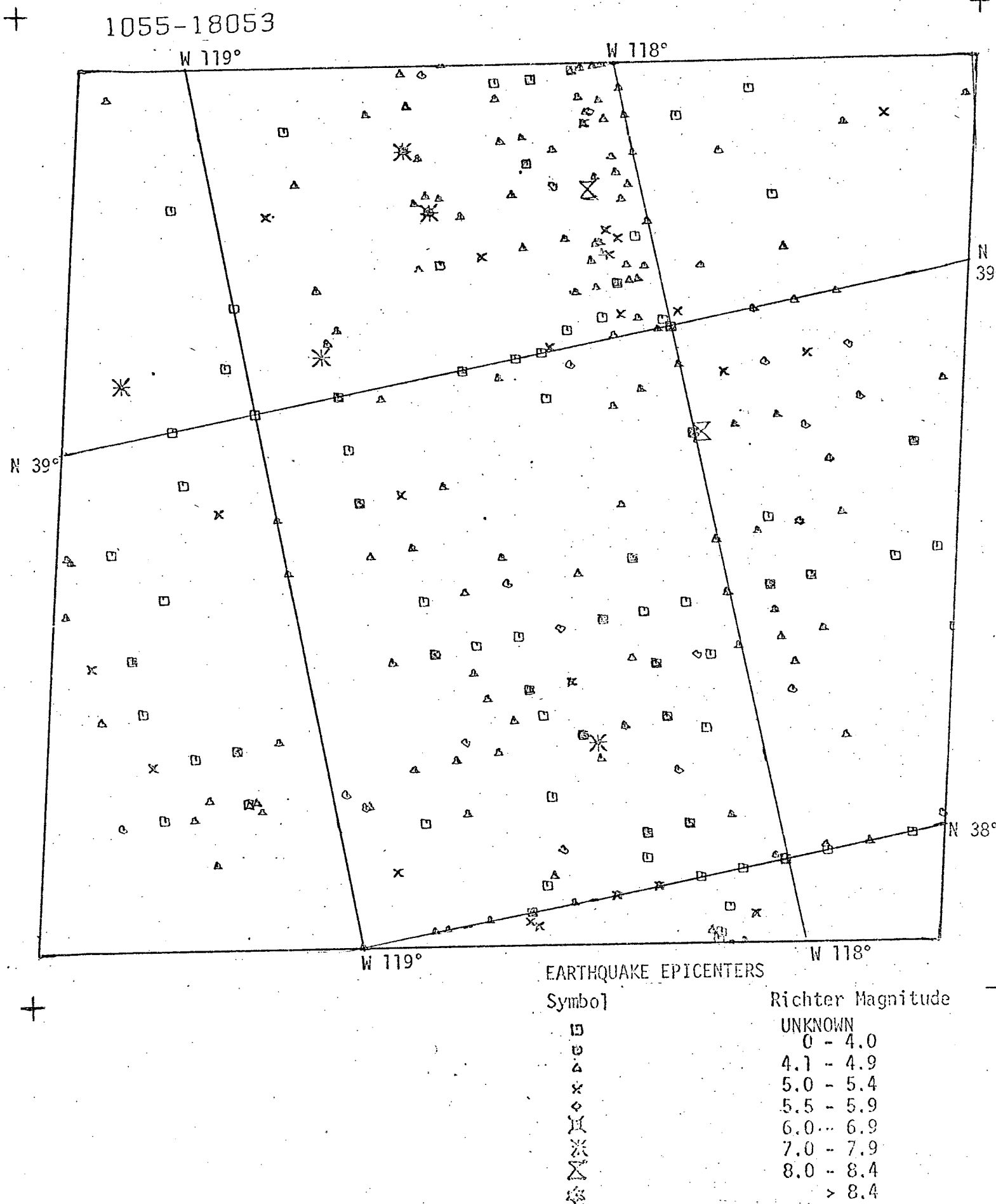


Figure 5b - Earthquake Epicenters Plotted on Photograph MSS 1055-18053



quite young as evidenced by lineaments in the alluvium and stream interruptions and deflections. Examples of fault traces suspected of recent breakage are indicated by the symbol R in Figure 5a.

Recent breakage occurs along at least three fault systems: Northwest-southeast parallel to the Walker Lane shear, north-south to NNE-SSW parallel to the Basin Range Nevada trend, and NE-SW. The latter system particularly characterizes the Tertiary volcanic area north and east of Mono Lake.

The area lies within the Ventura-Winnemucca Seismic belt of Ryall, Slemmons and Gedney, 1966, and was the site of several major earthquakes of magnitude 6.0 and above, Figure 5b.

Correlation of Figures 5a and 5b suggest that while several major shocks occurred on or near the Walker Lane fault zone, the general pattern of the seismicity appears to be more related to the meridional trend of Basin and Range faults, such as the sharp north-south faults observed in the Fairview-Dixie Valley area.

These lines of evidence suggest that at present Basin and Range tensional tectonism is most active here.

Evidence of pervasive recent faulting along both north-south tensional lines and a northwest-southeast shear line strongly suggests that the two tectonic elements are contemporaneously active and are genetically related. A tectonic model relating the fault and seismicity patterns is illustrated in Figures 11 and 12.

The ENE trend of the Excelsior Mountains is anomalous to the general NNW or NW trend of other ranges in that area and projects perpendicular to the Pilot and Cedar mountains. This unusual trend was pointed out by Gilbert et al. (1968) who recognized that the fault pattern forms as structural knee in the area between the White Mountains and Mono Lake. In their study of microseismicity of the Nevada Seismic zone, Gumper and Scholz (1971, p. 1421) found a similar bend as the seismic zone is displaced eastward from Owens Valley to Cedar Valley. Microearthquakes tend to cluster north of the Excelsior Mountains.

When they examined the microearthquakes between Mono Lake and Pilot mountains in detail, their fault plane solutions indicate predominantly

"strike-slip" faulting with the two nodal planes striking N 11° E and N 86° E.

Considering the work of Gilbert et al. (1968) and the N 65° E trending scarp forward after the 1934 Excelsior Mountain earthquake, (Callaghan and Gianella, 1935), they assumed the N 86° E nodal plane to be the fault plane and their fault plane solution suggested left-lateral faulting consistent with observations by Gilbert et al. (1968) in the area east of Mono Lake.

The ENE faults observed in ERTS imagery range from N 60° E and N 70° E consistent with field observations of Gilbert et al. (1968) and Callaghan and Gianella (1935).

#### CARSON SINK, NEVADA

Reference: MSS 1019-18050

Overlays: Figures 6a and 6b

Figure 6a shows a plot of known faults (Webb & Wilson, 1962 and King, 1969) and some lineaments and faults inferred from the ERTS-1 image. The quality of the available images in this particular area did not allow more detailed analysis. However, the northeast trending lines marked C<sub>1</sub> (Fig. 6a) seem to belong to an important fault system extending from the vicinity of Fallon to Carlin, Nevada. This system is discussed later in the text in the section on the northeast-southwest lineaments.

The area shows the continuation of the Ventura-Winnemucca Seismic belt.

Figure 6b is a plot of earthquake epicenters.

Figure 9 also shows the distribution of Quaternary volcanic rocks which seem to generally follow the California-Nevada Seismic zone.

#### CENTRAL NEVADA

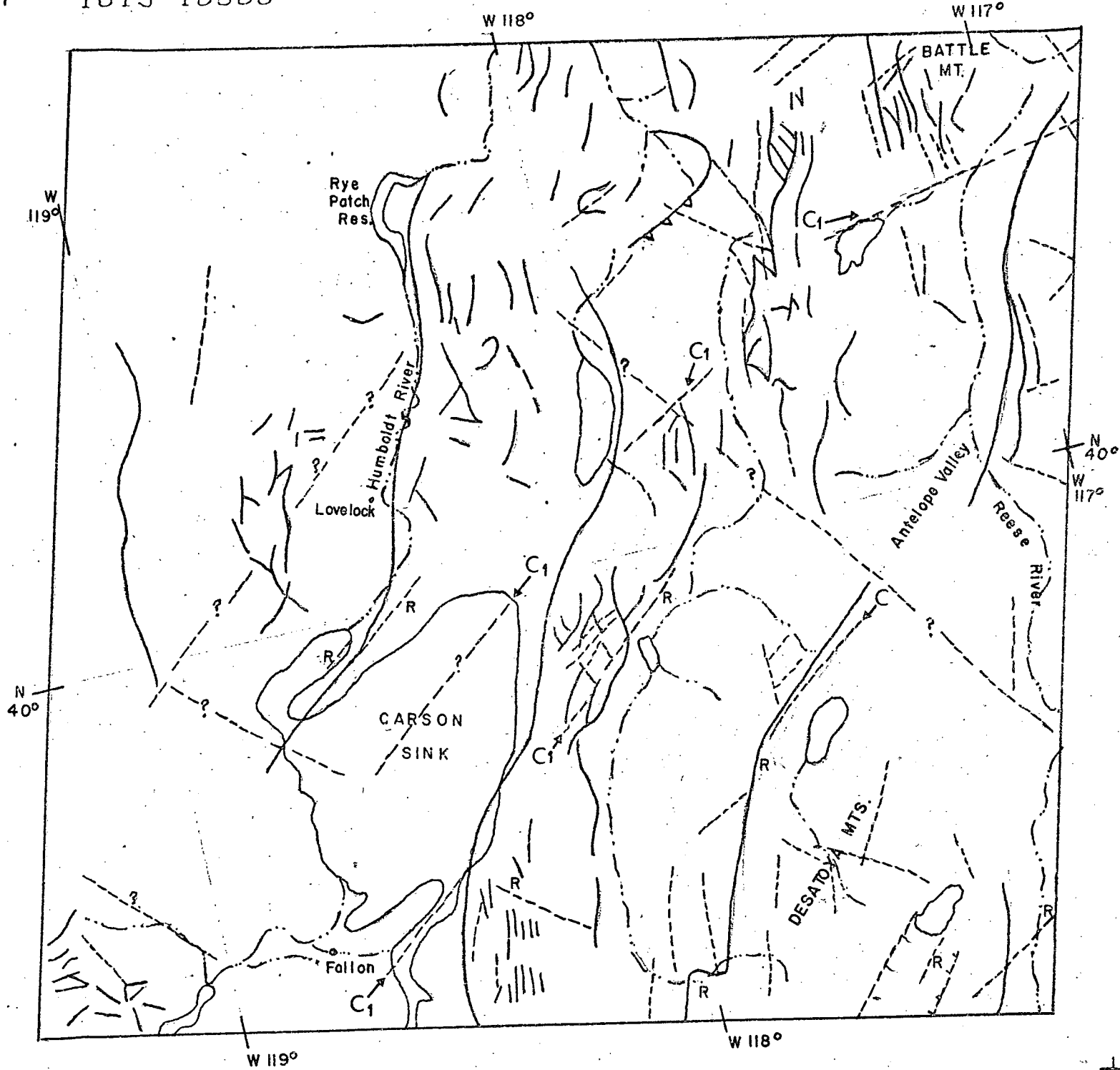
Reference: MSS-1054-17594

Overlays: Figures 7a and 7b

The scene shows three known tectonic elements:

- a) North-northeast trending Basins and Ranges and the large normal faults mainly responsible for the present physiography.
- b) The scene lies within the Antler Orogenic Belt, a major Paleozoic

1019-18050



- KNOWN FAULT
- - - INFERRED FAULT OR LINEAMENT FROM ERTS IMAGERY
- ~ ~ ~ DRAINAGE

FIGURE 6a FAULT STRUCTURES ON PHOTO MSS 1019-18050

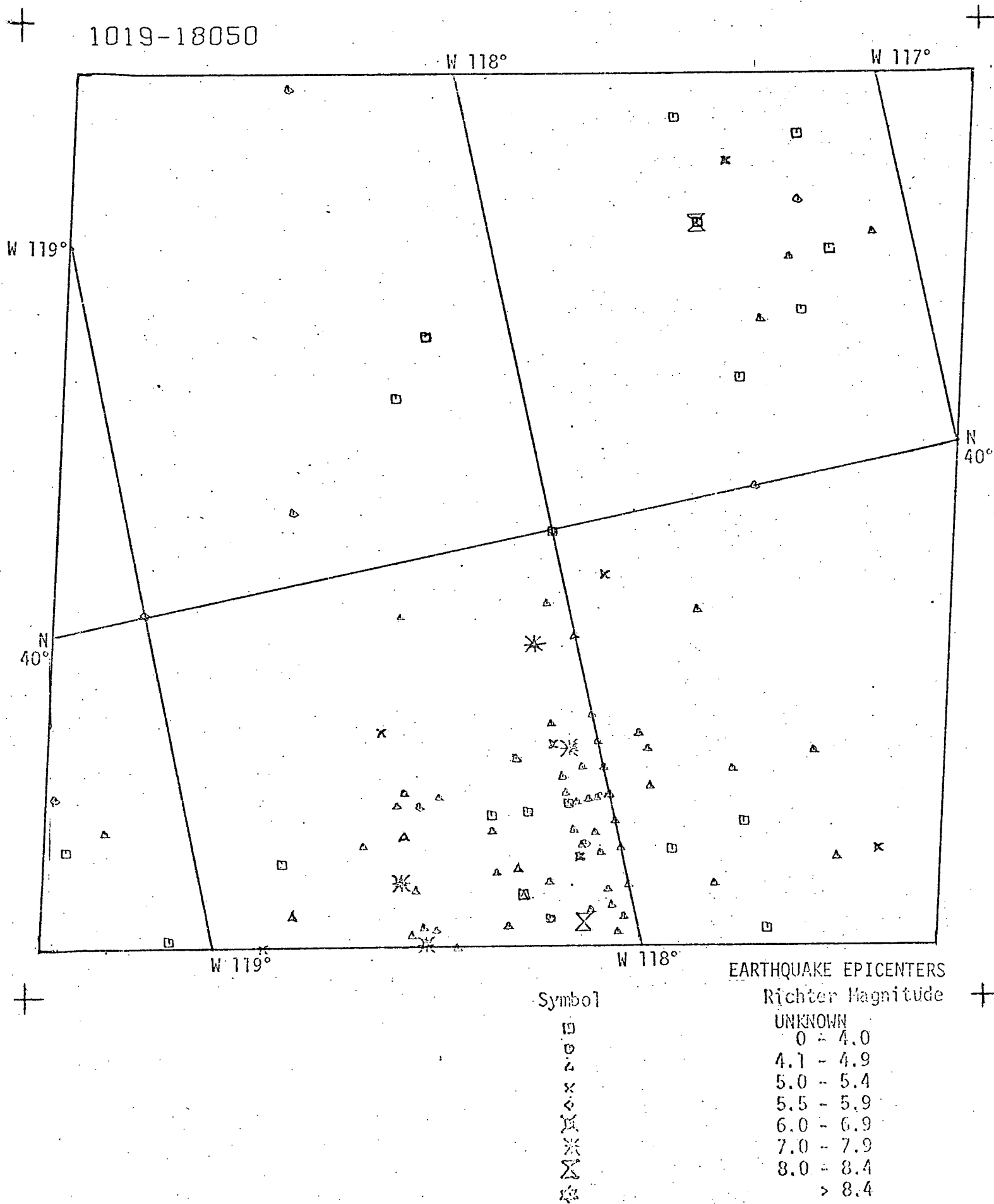


Figure 6b - Earthquake Epicenters Plotted on Photograph MSS 1019-18050

1054-17594

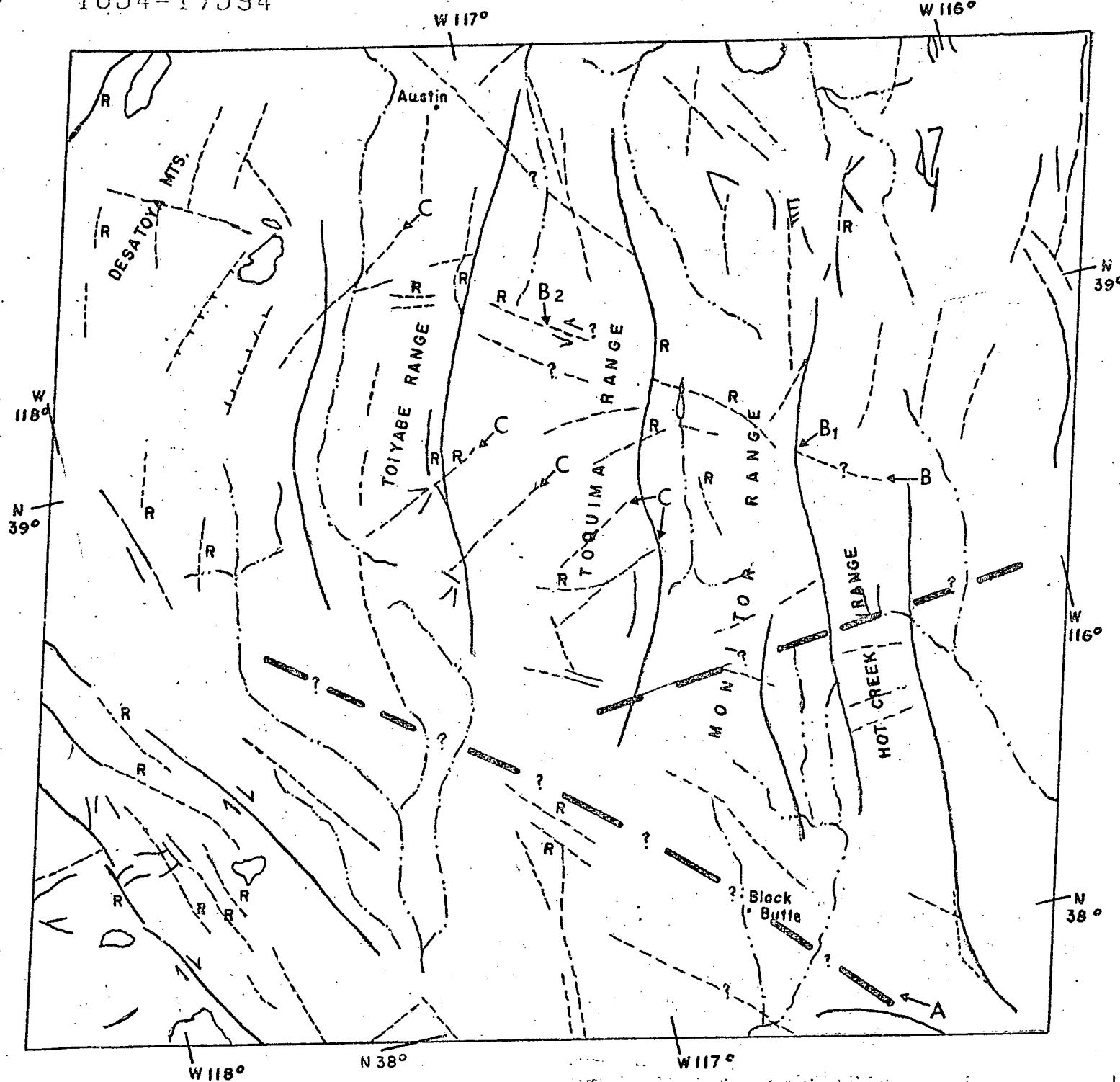


FIGURE 7a FAULT STRUCTURES ON PHOTO MSS 1054-17594

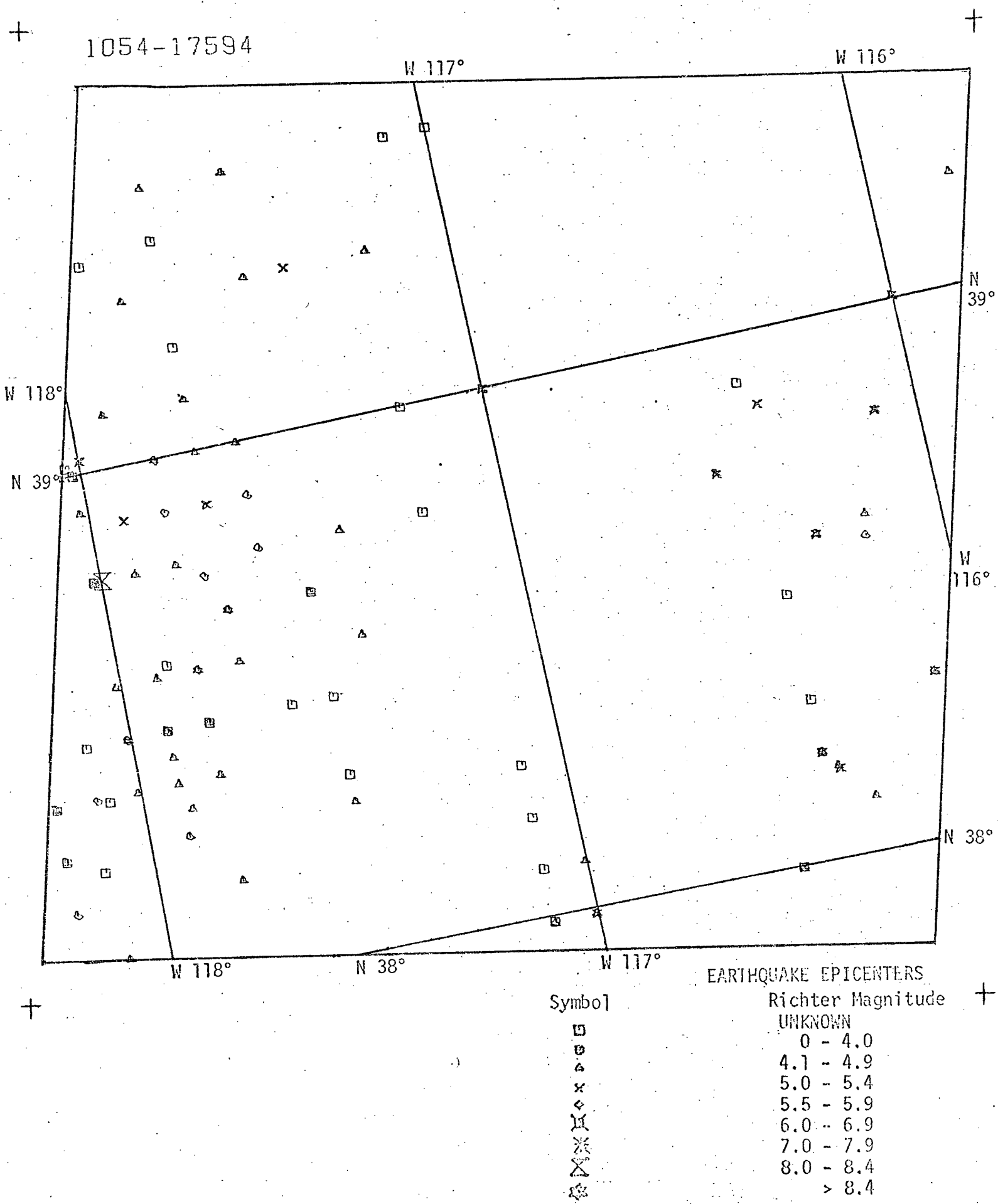


Figure 7b - Earthquake Epicenters Plotted on Photograph MSS 1054-17594

uplift separating a miogeosyncline on the east and an engiosyncline on the west.

c) The continuity of the north-south trending structures is interrupted by the Walker Lane fault zone.

Additional observations derived from the ERTS scene are:

a) An ill-defined structural discontinuity (arrow A, Fig. 7a) running north-west somewhat parallel to the Walker Lane fault zone. The nature of this discontinuity is not known but may be related or part of the Walker Lane fault system.

b) Faults showing evidence of recent breakage cut the Toiyabe, Toquima, Monitor and Hot Creek Ranges and intervening valleys. These young faults trend NNE-SSW, NE-SW and northwest-southeast.

c) The ERTS image shows a probably very young fault zone cutting across several ranges and valleys almost at right angle to the Basin and Range trend. An almost continuous zone of sharp lineaments extends from across Hot Creek Range on the southeast to the Toiyabe Range and probably extends farther northwest towards Desatoya Mountains (B, Figure 7a).

The sharpness and linearity of the fault strands particularly evident across the alluvium of the basins suggest a very young age. Minor lateral offsets in some range fronts across the fault strands, e.g., at B1 and B2, suggest an incipient left-lateral fault zone.

d) Northeast trending faults (C, Fig. 7a) of the Carlin-Fallon fault system are discussed later in the text.

e) Seismic activity (Figure 7b) is relatively mild east of the Toiyabe Range but the seismicity pattern maintains a preferred north-south to NNE-SSW trend.

West of the Toiyabe Range of approximately longitude  $117^{\circ} 30'$  seismicity is considerably higher.

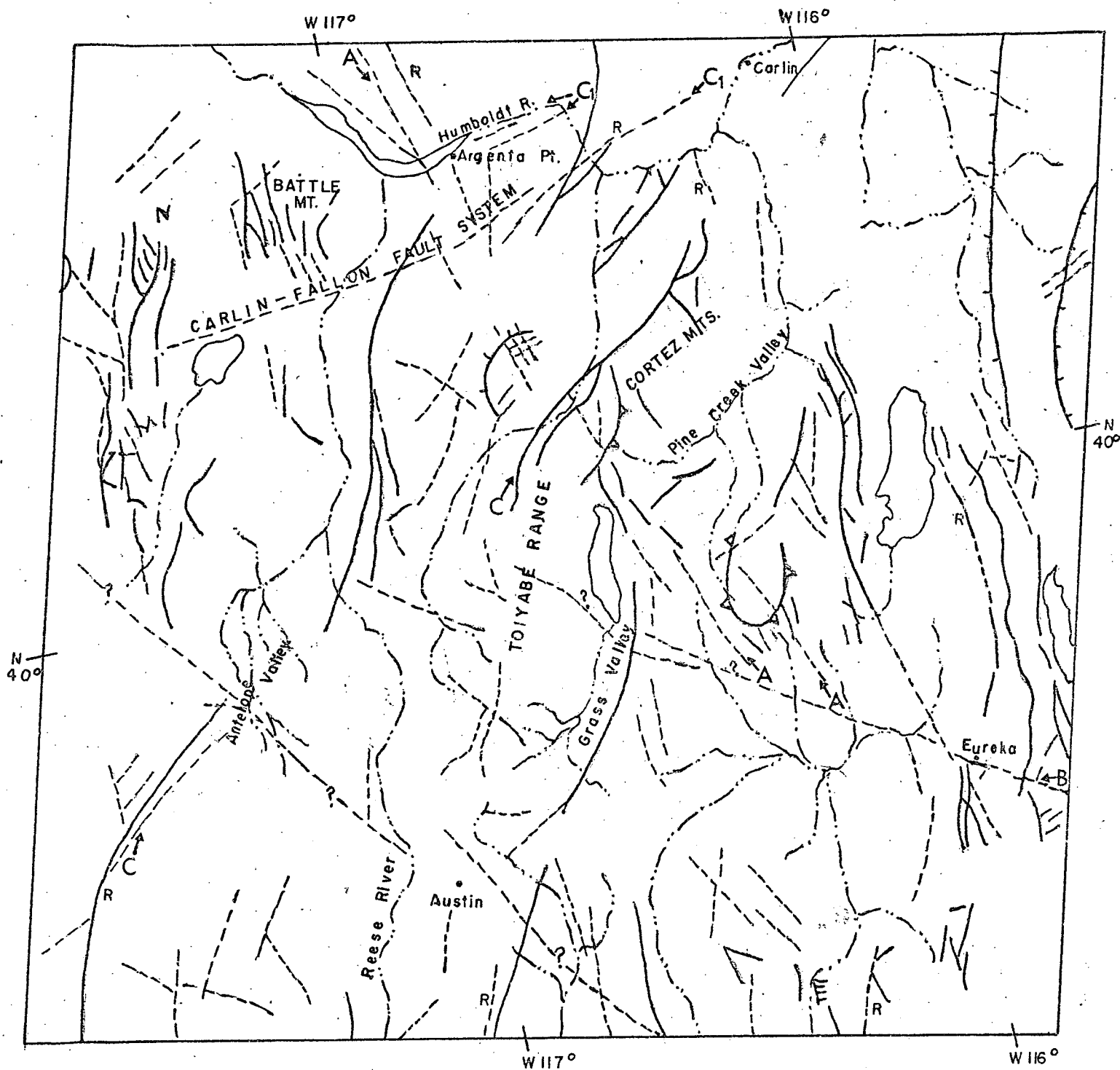
None of the individual major faults or observed lineaments in particular appear to have a clear relationship to the distribution of earthquakes.

#### EAST-CENTRAL NEVADA

Reference: MSS 1018-17592 (Color Composite)

Overlays: Figures 8a and 8b

+ 1018-17592 +

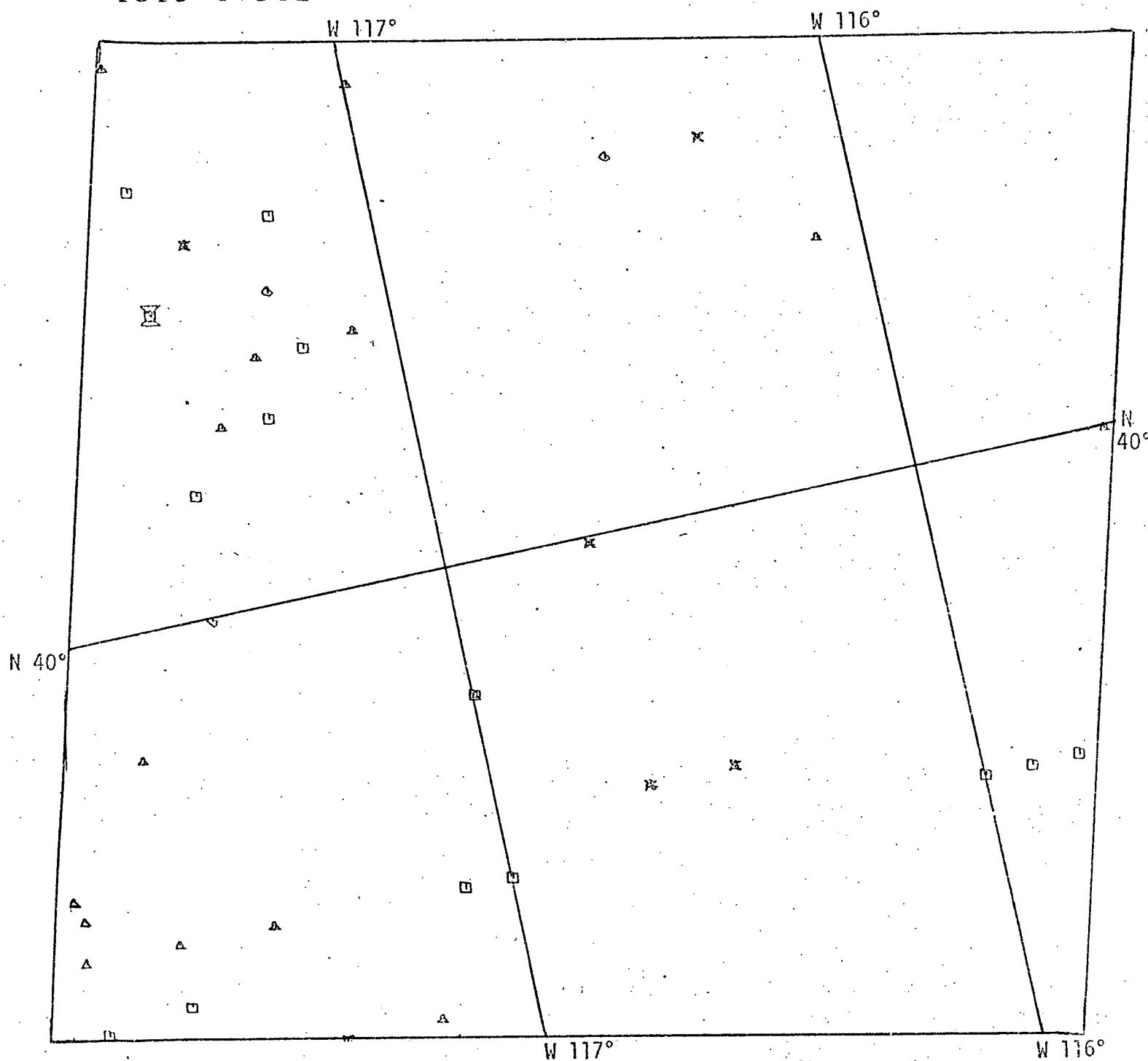


- KNOWN FAULT
- - - INFERRED FAULT OR LINEAMENT FROM ERTS IMAGERY
- ~ ~ ~ DRAINAGE

FIGURE 8a FAULT STRUCTURES ON PHOTO MSS 1018-17592



1018-17592



# EARTHQUAKE EPICENTERS

Symbol	Richter Magnitude
□	UNKNOWN
○	0 - 4.0
△	4.1 - 4.9
×	5.0 - 5.4
◇	5.5 - 5.9
⊗	6.0 - 6.9
⊠	7.0 - 7.9
⊞	8.0 - 8.4
⊠	> 8.4

Figure 8b - Earthquake Epicenters Plotted on Photograph MSS 1018-17592

The scene shows part of the Humboldt River near Carlin and Battle Mountain in the north, Eureka Mining district, and Austin, Nevada. Most of the scene lies within the Antler Orogenic Belt.

One major feature recognized in the ERTS image is a prominent en echelon fault zone trending north-northwest from the vicinity of Eureka and crosses the Humboldt River near Argenta point without any visible effect on the river valley. Strands of the fault zone cut the Quaternary volcanics north of the river (arrows A, Figure 8a).

The second fault structure is more subtle and extends from near Eureka, Nevada west-northwestward and across Grass Valley and the north end of the Toiyabe Range. Although this structure practically has little or no physiographic expression, lineaments and tonal and color differences in the alluvium are notable. Where it cuts the ranges, structural discontinuities are often observed. Near Eureka the lineament corresponds to the well known Ruby Hill normal fault which displaces the Eureka mineralized zone and has in fact delayed mining development for many years (Nolan and Hunt, 1968).

From the ERTS-1 symposium abstracts Rowan and Wetlaufer (1973, p. 46) mentioned that they recognized northeast and northwest trending lineaments in northeast Nevada. We are not certain whether the features referred to here are the same or are related to Rowan and Wetlaufer's lineaments.

What we wish to emphasize here is that the seismicity in this region is relatively mild except near Battle Mountain where a major earthquake of magnitude above 6.0 shows in Fig. 8b.

This area however represents the northernmost limit of the California-Nevada seismic belt.

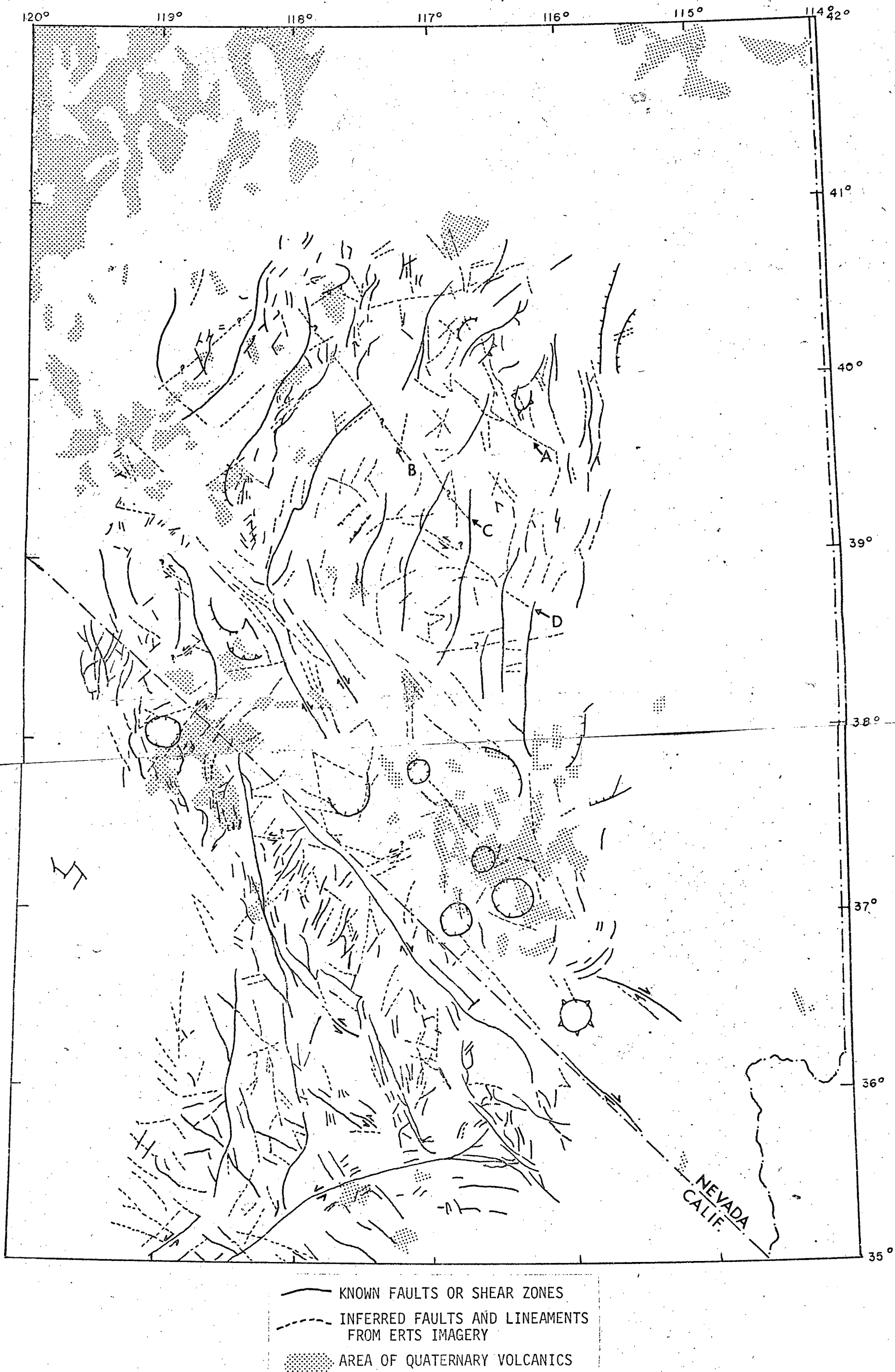
#### TECTONIC ANALYSIS

Figure 9 is a preliminary map showing the fault pattern in part of the Basin and Range province east of the Sierra Nevada. The map which covers southeastern California and western Nevada contains a combination of published data\* and inferred lineaments and faults derived from ERTS-1 imagery. Since the latter class of data is by its very nature tentative until verified by field methods, it is represented by broken lines. During the course of this study, it was noted that areas covered by Quaternary and late Tertiary volcanic rocks coincide generally with Quaternary faulting including many suspected recent fault breaks as well as zones of historic seismic activity.

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\*References to fault maps used include Webb and Wilson, 1962; King, 1969; Matthews and Burnett, 1963; and Hill, Lao, Moore, and Wolfe, 1964; and others.

FIGURE 9 GENERAL FAULT MAP AND QUATERNARY VOLCANICS OF AREA STUDIED



For this reason we have included in Figure 9 known exposures of the younger volcanics.

Figure 10 shows the epicenters of historic earthquakes for the same area plotted at the same scale as Figure 9. Here, however, we have shown only two classes of earthquakes: those under magnitude 6 are represented by dots and the major shocks above 6.0 by the symbol X.

The fault pattern has three essential elements:

Major northwest-trending shear zones:

Previously known shear zones of this class are prominent in ERTS imagery. These are: Las Vegas shear (right-lateral), Furnace Creek (right lateral), Death Valley (right-lateral), and Walker Lane (right lateral). In addition, analysis of ERTS-imagery suggests the presence of other incipient shear zones in central Nevada (e.g., A B C & D, Fig. 9) of the same trend. The sense of lateral motion indicated by the symbols are tentative and need field confirmation.

It should be noted however that while the major known shear zones are right-lateral, there are several suggesting an opposite or left-lateral sense of motion. Some of these have been reported in the literature; Mayo (1947, Fig. 2a) for example, identified fault (#1) east of Owens Lake as left-lateral. Examples of known and suspected left-lateral shear faults of northwest trend are:

#1 Figure 2a	#5 Figure 5a
#3 Figure 2a	Arrow B, Figure 8a

The presence of left-lateral shear faults in the Basin and Range Province if indeed confirmed would be highly significant because it has been often stated in the literature that a general right lateral shear exists in the western United States (e.g. Hamilton, 1966). While there is abundant evidence for segmatic right-lateral shear, the existence of left-handed motion on certain fault zones has to be accommodated within a general tectonic model for the development of Basin and Range structures.

Figure 11 illustrates that both right and left-handed shear can develop when various segments of a rift widen at unequal rates.

It became clear from our analysis of ERTS imagery that the shear zones in the Basin and Range Province are not continuous but are arranged en echelon. On the northwest they start in the volcanic rift area directly

FIGURE 10 SEISMICITY MAP OF AREA STUDIED

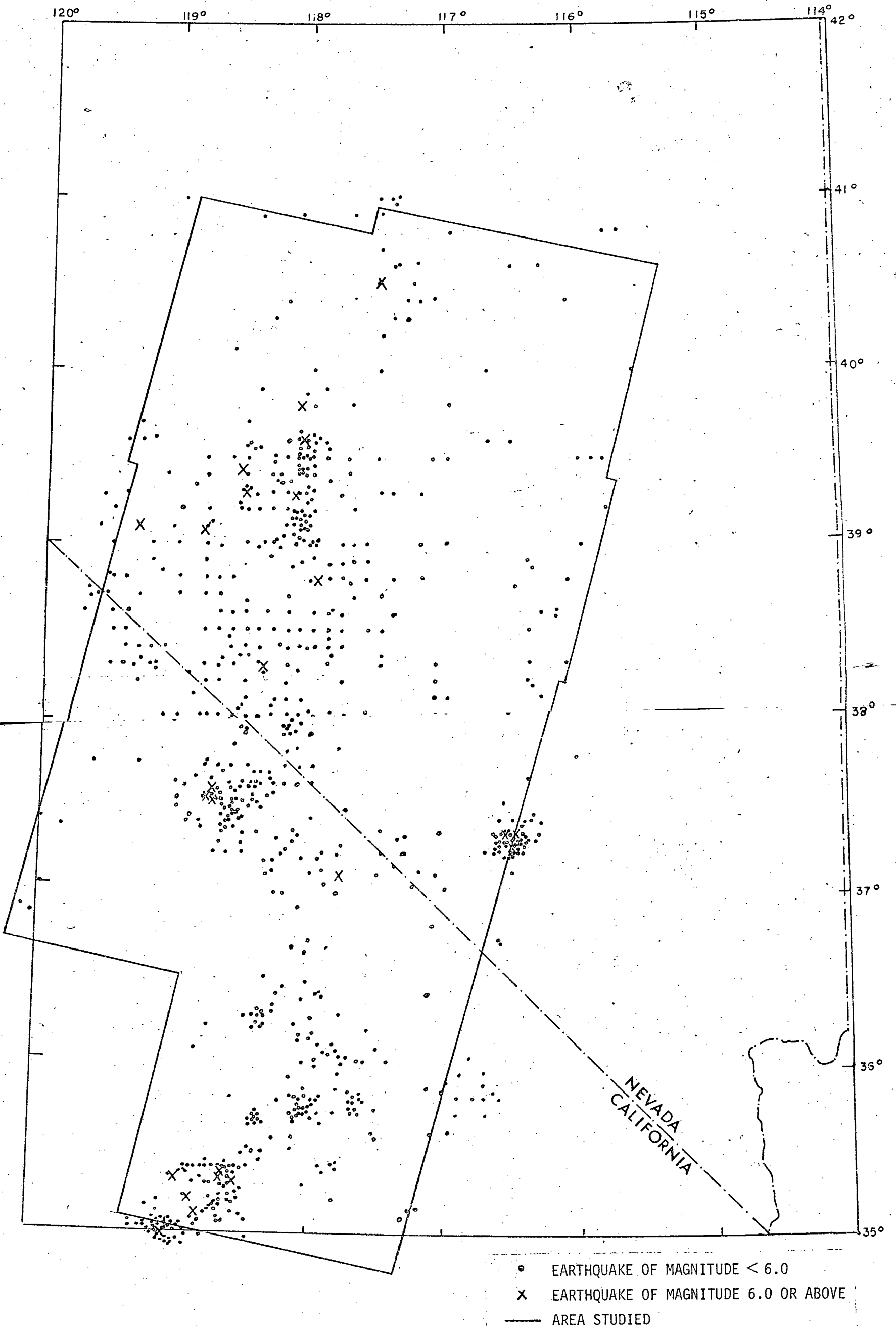
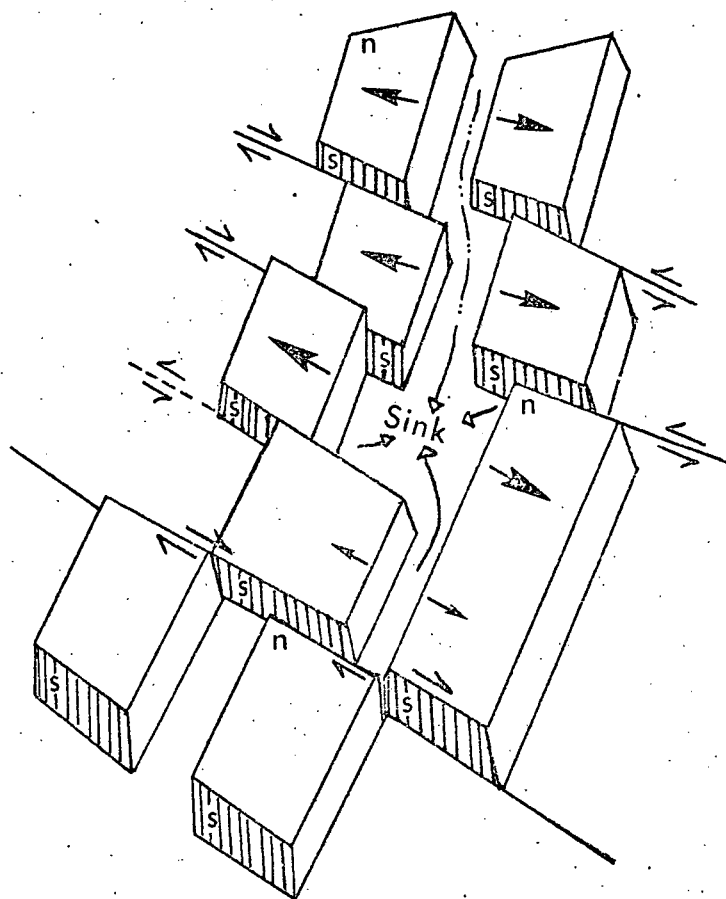


FIGURE 11 TECTONIC DEVELOPMENT MODEL OF BASIN AND RANGE



east of the Sierra Nevada block and appear to die out or change into flexures associated with thrusts toward the southeast.

Observation from ERTS imagery indicate that the northwest-trending shear zones have been active in the Holocene.

#### North-northeast rift faults:

The north trending Basin and Range structures in Nevada have long been recognized as features of regional tension. The interfaces between mountain blocks and adjacent basins are often marked by normal faults. ERTS imagery contributed abundant evidence of Holocene (recent) faulting along Basin and Range faults within the California-Nevada seismic belt (Fig. 9 and 10).

The pattern of seismicity revealed from this investigation (Figure 10) agrees generally with earlier work by Ryall et al. (1966) and Gumper and Scholz (1971).

However, there are several observations of significant detail which merit attention:

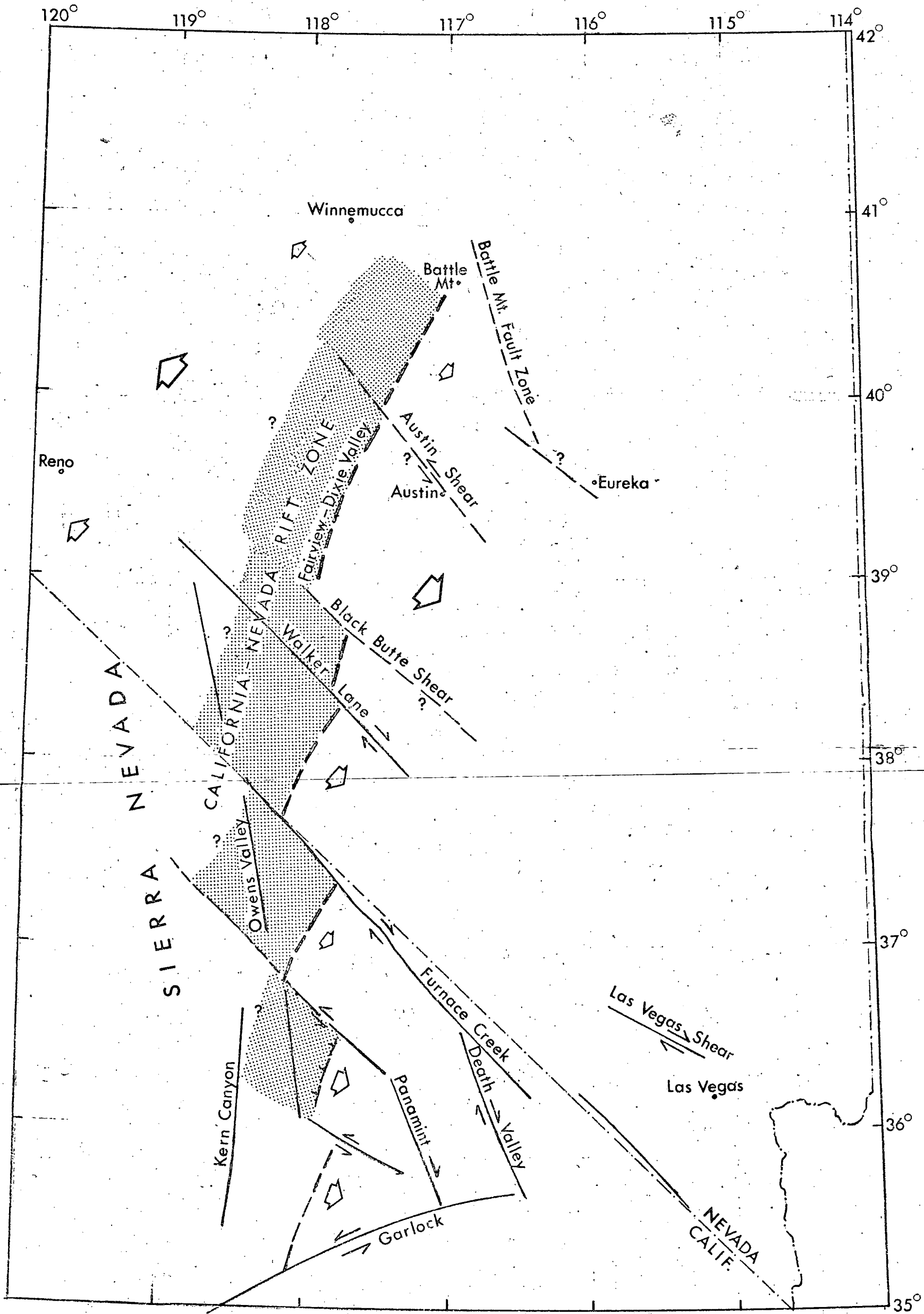
While the California-Nevada seismic belt has a general northerly trend, we recognize within the belt where earthquake epicenter plots show higher density. These segments are also characterized by shocks of higher magnitude ( $> 6$ ).





When the seismic belt is examined from south to north, we discern a pattern of en echelon segments of denser seismicity and recent faulting which trending northeast and becoming offset across major shear zones. This pattern is illustrated in Figure 12.

When we consider the general fault pattern and particularly areas of Holocene faulting, together with the offset nature of highly seismic segments and the distribution of Quaternary volcanics, we find that they fit a tectonic style reminiscent of tension rifts and transform faults observed in areas of spreading centers on the ocean floors. The geological record indicates that the Sierra Nevada block was part of a huge Tertiary uplift which included a considerable part of Nevada. In late Tertiary time the eastern part of the uplift collapsed and produced the present Basin and Range physiography (Lindgren, 1911; Christensen, 1966). When we consider the

FIGURE 12 INTERPRETIVE DIAGRAM SHOWING A RIFT AND TRANSFORM FAULT MODEL FOR THE CALIFORNIA-NEVADA RIFT BELT

FOLDOUT FRAME



-  KNOWN SHEAR ZONES
-  PROBABLE SHEAR ZONES INFERRED FROM ERTS
-  APPROXIMATE EAST LIMIT OF RIFT BELT
-  INFERRED DIRECTION OF RIFT EXTENSION (SIZE OF ARROW SUGGESTS RELATIVE RATES OF EXTENSION INFERRED FROM SENSE OF MOVEMENT ON SHEAR ZONES)

FOLDOUT FRAME

31

2



observations made in this investigation together with ideas advanced by Thompson (1960, 1964), Cook (1965), Hamilton and Myers (1965), and others, it seems certain that the California-Nevada seismic belt represents the site of an actively opening rift characterized by interrelated features of lateral extension, differential shear, volcanicity and seismic activity.

#### Minor transverse structures:

The north-northeast trending Basin and Range blocks are cross-cut by second order faults belonging to two prevailing trends: northwest-southeast. These faults are limited in length cutting obliquely across an individual valley, some extend across one or both ranges bounding the valley. Some extend across several basins and ranges often terminating a range or otherwise coincide with oroflexes and bends. The shape of many valley floors and the location of sinks (lowest areas in valleys where drainage from all directions converge) appear to be controlled by these transverse structures. The physiographic pattern is consistent with a tectonic style for the development of Basin and Range structures illustrated in Figs. 11 and 12.

#### Northeast-southwest lineaments:

Significant northeast trending faults are observed in the Basin and Range province of Nevada. Examples can be seen in the Slate Ridge area (arrow B, Fig. 3a). Other examples cut across the Monitor, Toiyabe, and other ranges in Central Nevada (arrows C, fig. 7a).

Among the prominent northeast trending faults that are observed in Northeast Nevada [arrows C and C<sub>1</sub>, Fig. 5a and 8a), a large northeast trending system is observed in the area between Carlin and Fallon (arrows C<sub>1</sub>, Fig 5a, 6a, and 8a). This zone extends from Carlin and Battle Mountain, Nevada, southwest towards the Carson Sink area (Fig. 6a), and then heads in the direction of Fallon, Nevada (Fig. 5a). The following physiographic features appear to be strongly influenced by the Carlin-Fallon Fault System: the east fork of the Humboldt River, the Humboldt River Valley between Elko and Carlin, Nevada, Boulder Valley, Cortez Mts., the north part of Dixie Valley, West Humboldt Range, and the Carson Sink. Near Fallon, Nevada (Fig. 5a),

the relationship between the Carlin-Fallon Fault System and the northwest extension of the Walker Lane Fault Zone is uncertain. However, in Figure 5a we note that across the Walker Lane Fault Zone a prominent zone of northeast-southwest faulting passes between Walker Lake and Mono Lake. Faults of this zone cut across the Wassuk Range, which lies west of Walker Lake, Nevada (arrows  $B_1$ ,  $B_2$ , and  $B_3$ , Fig. 5a) and they appear to control the trend of the Excelsior Mts., northeast of Mono Lake, as well as, the down-faulted block containing Mono Lake (arrows  $B_2$  and  $B_3$ , Fig. 5a).

The widespread occurrence of this class of faults and their relatively young age, as inferred from their continuation across the alluvium of the valleys and sharpness of physiographic lineaments associated with them, suggest a regional rather than local character.

Viewed within the framework of the Basin and Range tectonics, of northwest extension of Nevada, the northeast trending faults would represent rift or tension zones characterized by vertical fault displacements.

This class of faults, however, has two puzzling characteristics: First, a left-lateral strike-slip component appears to be associated with many of these faults (arrow B, Fig. 3a, and arrows  $B_1$  and  $B_2$ , Fig. 5a).

Second, their trend is oblique to the prevailing northerly grain of Basin and Range rift structures.

The full meaning of these puzzling characteristics is not yet fully clear and will be subject of further analysis.

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NOAA Hypocenter Data Cards, January 1972 through March 1973.

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Known fault lines in this report were plotted from the following maps:

- 1] Progress Geologic Map of Nevada (Map 16)  
Scale - 1:500,000  
Nevada Bureau of Mines, University of Nevada, Reno  
July 1962  
Compilation by B. Webb and R. V. Wilson
- 2] Tectonic Map of North America  
Scale - 1:5,000,000  
U.S. Geological Survey  
1969  
Compilation by Philip B. King
- 3] Geologic Map of California  
Scale - 1:250,000  
Division of Mines and Geology & USGS  
1965  
Olaf P. Jenkins Edition  
Compiled by Robert A. Matthews and John L. Burnett
- 4] Earthquake Epicenter and Fault Map of California  
(Central and Southern Area)  
California State Dept. of Water Resources - Crustal Strain and  
Fault Movement Investigation  
Compiled by D. M. Hill, C. Lao, V. A. Moore, and J. E. Wolfe  
1964 January  
Bulletin No. 116-2